

NEUTRAL CURRENT π^0 INTERACTIONS AT MINIBOONE

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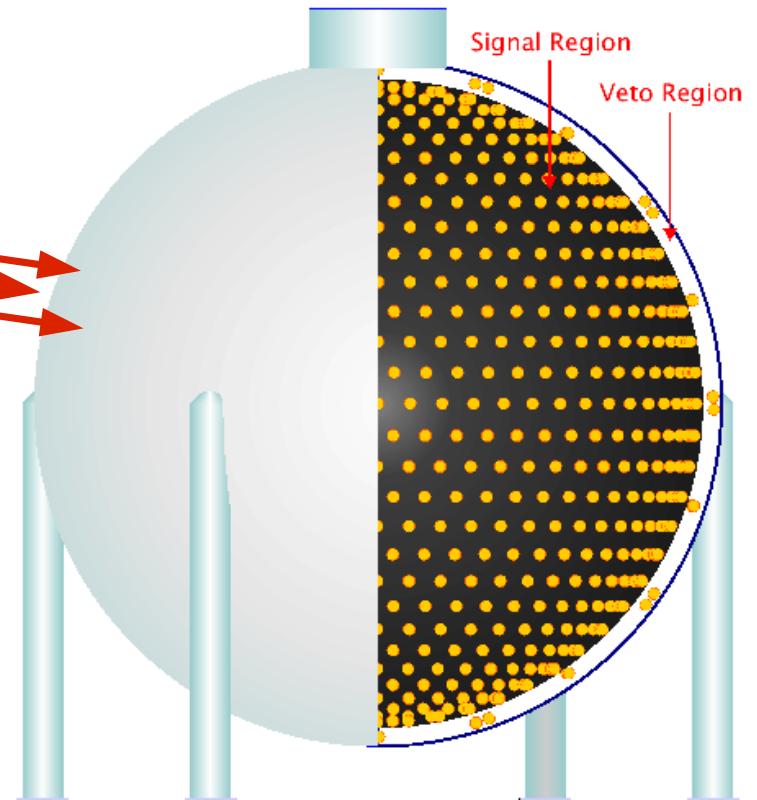
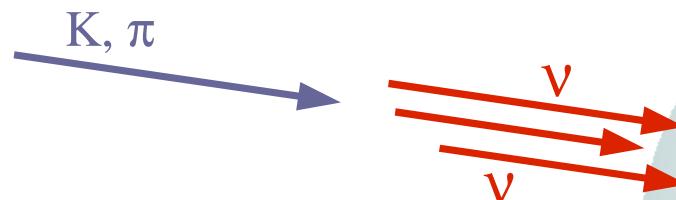
- › MiniBooNE
- › NC π^0 cross section measurements and predictions
- › Data/NUANCE/NEUGEN/NEUT comparisons

NuInt '04

BOONE BEAM & DETECTOR

Beam

- › 8 GeV protons from the Fermilab Booster directed into horn containing 71 cm Be target
- › Secondary particles from target interactions ($\pi, K \rightarrow$) 50 m decay region ($\pi \rightarrow \mu \nu_\mu$)
- › Absorber and 450 m of dirt "clean" the beam of everything except ν 's

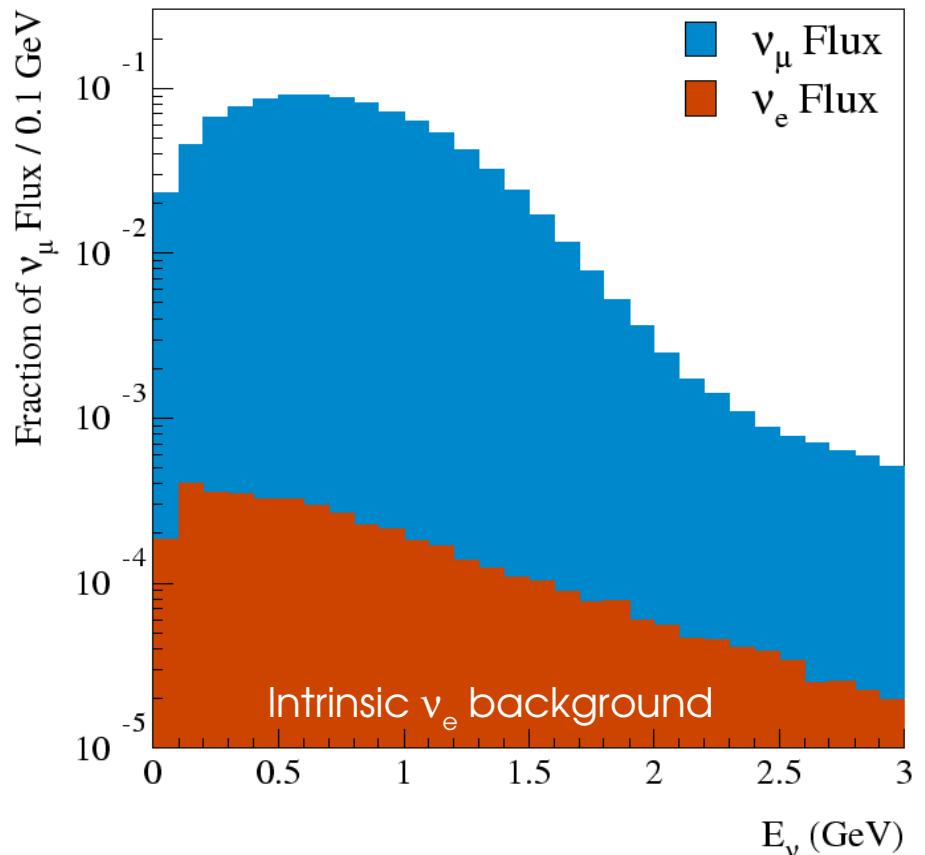


Detector

- › 12 m diameter sphere
- › 8 inch Hamamatsu PMT's
- › 1280 PMT's in signal region (10% coverage)
- › 240 PMT's in veto region
- › ~800 tons pure mineral oil

BEAM COMPOSITION

- › protons on beryllium
 $p + Be \rightarrow \pi^+, K^+, K_L^0$
- › yield a high flux of ν_μ
 $\pi^+ \rightarrow \mu^+ \nu_\mu$
 $K^+ \rightarrow \mu^+ \nu_\mu, K_L^0 \rightarrow \pi^- \mu^+ \nu_\mu$
- › with a low ν_e background
 $\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$
 $K^+ \rightarrow \pi^0 e^+ \nu_e, K_L^0 \rightarrow \pi^- e^+ \nu_e$



ν_e background comparable to oscillation signal → need to know flux very well!!

See J. Monroe's talk later this session for more on MiniBooNE flux predictions

- › detailed simulations (GEANT3/GEANT4)
- › CERN HARP measurements with MiniBooNE target replica
- › BNL E910 production data with thin Be target
- › Off-axis muon counter (LMC) → background ν_e 's from K decays
- › 25/50 meter decay region → background ν_e 's from μ decays

BOONE COLLABORATION

University of Alabama
Bucknell University
University of Cincinnati
University of Colorado
Columbia University

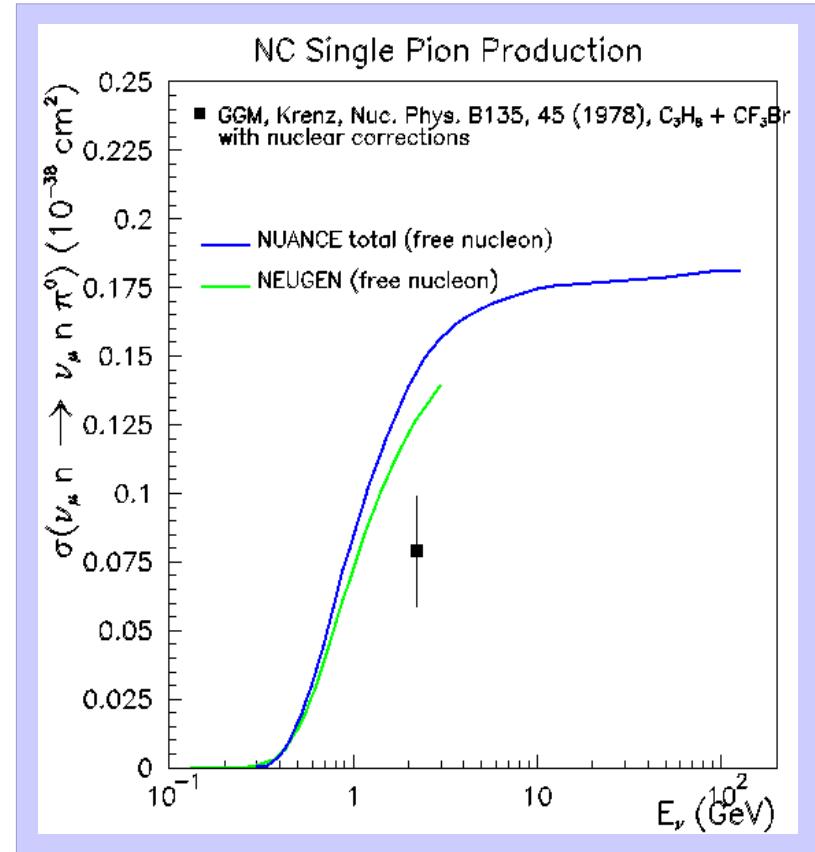
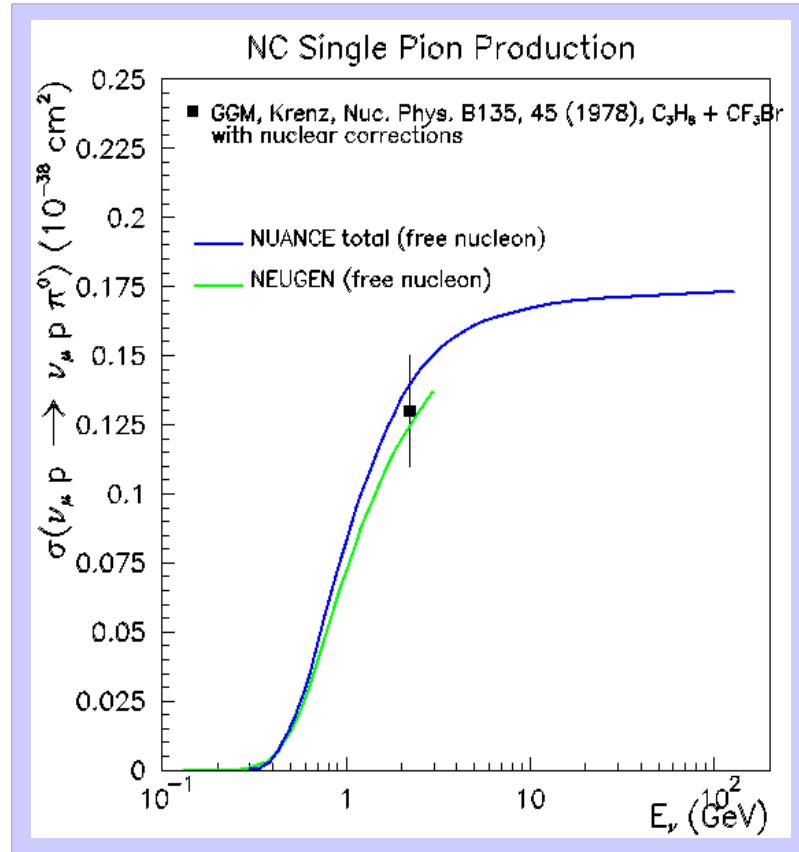
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Fermi National Accelerator Laboratory

Indiana University
Los Alamos National Laboratory

Louisiana State University
University of Michigan
Princeton University

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F.C. Shoemaker, H.A. Tanaka

NC π^0 PRODUCTION: EXISTING MEASUREMENTS

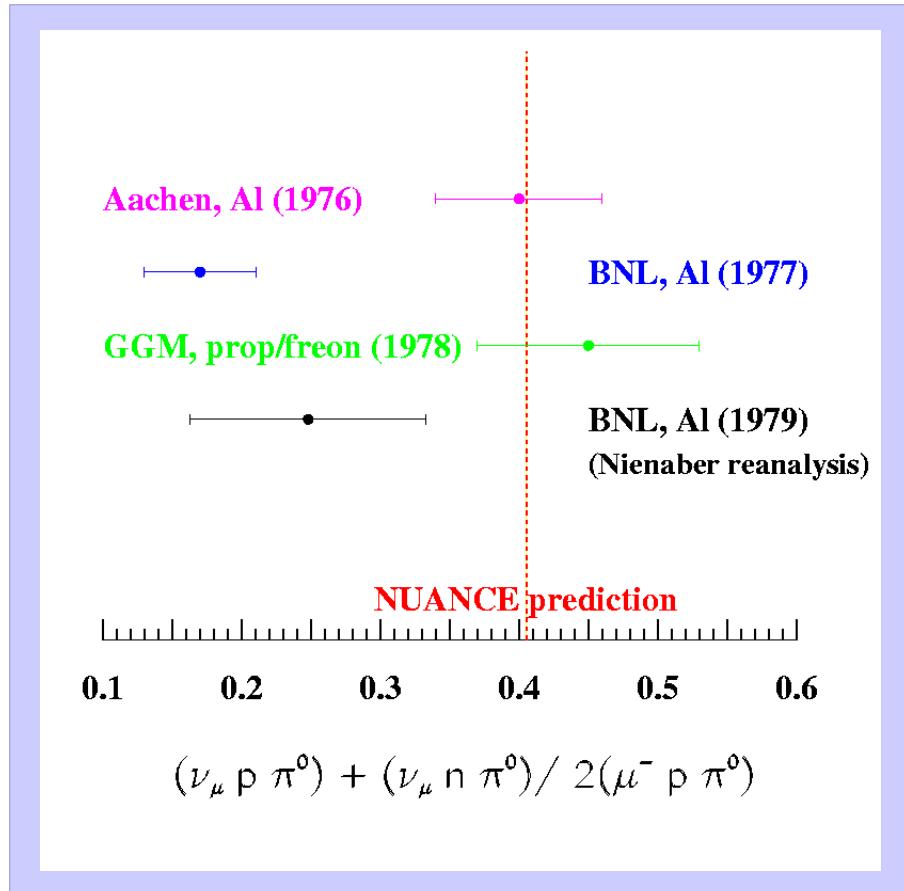


Re-analysis of Gargamelle 1970's bubble chamber data

E. Hawker, with help from Morfín, Pohl (shown at Nulnt'02)

Absolute neutral current π^0 cross section not measured well at all!!

NC π^0 PRODUCTION: NC/CC RATIOS



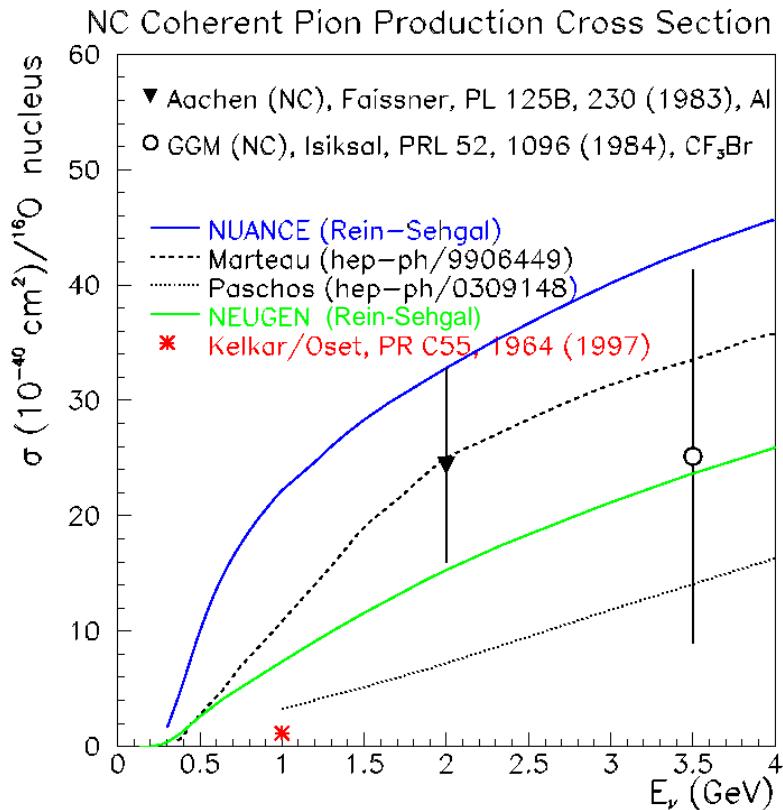
Most data for NC single π^0 production only available as NC/CC cross section ratios

Some measurements differ by factors of 2-3!!

$$R_{\pi^0} = \frac{(\pi^0/\mu)_{data}}{(\pi^0/\mu)_{MC}} = 1.03 \pm 0.02(stat) \pm 0.09(syst)$$

C. Mauger, Nucl. Proc. Suppl. 112 (2002)

NC π^0 PRODUCTION: EXTERNAL PREDICTIONS



Share common theoretical inputs:

- Llewellyn Smith free nucleon QE cross section
- Rein-Sehgal resonance cross sections
- standard DIS formula for high Q^2

But, nontrivial differences:

- implementation of Fermi gas model for QE
- joining of resonance and DIS regions
- treatment of nuclear effects (FSI)

NUANCE V3

Resonant π^0 production: $m_A = 1.1 \text{ GeV}$

Coherent π^0 production: $m_A = 1.03 \text{ GeV}$

Rein-Sehgal cross section prediction

NEUGEN

Resonant π^0 production: $m_A = 1.032 \text{ GeV}$

Coherent π^0 production: $m_A = 1.0 \text{ GeV}$

Rein-Sehgal, but very different energy dependence than NUANCE's
Rein-Sehgal calculation

NEUT

Resonant π^0 production: $m_A = 1.1 \text{ GeV}$

Coherent π^0 production: $m_A = 1.0 \text{ GeV}$ for $\frac{d\sigma}{dq^2}$
Marteau rescaled cross section

NC π^0 ANALYSIS EVENT SELECTION

Event selection:

Reduce background (Level 1 cuts)

$$N_{TANK} > 200$$

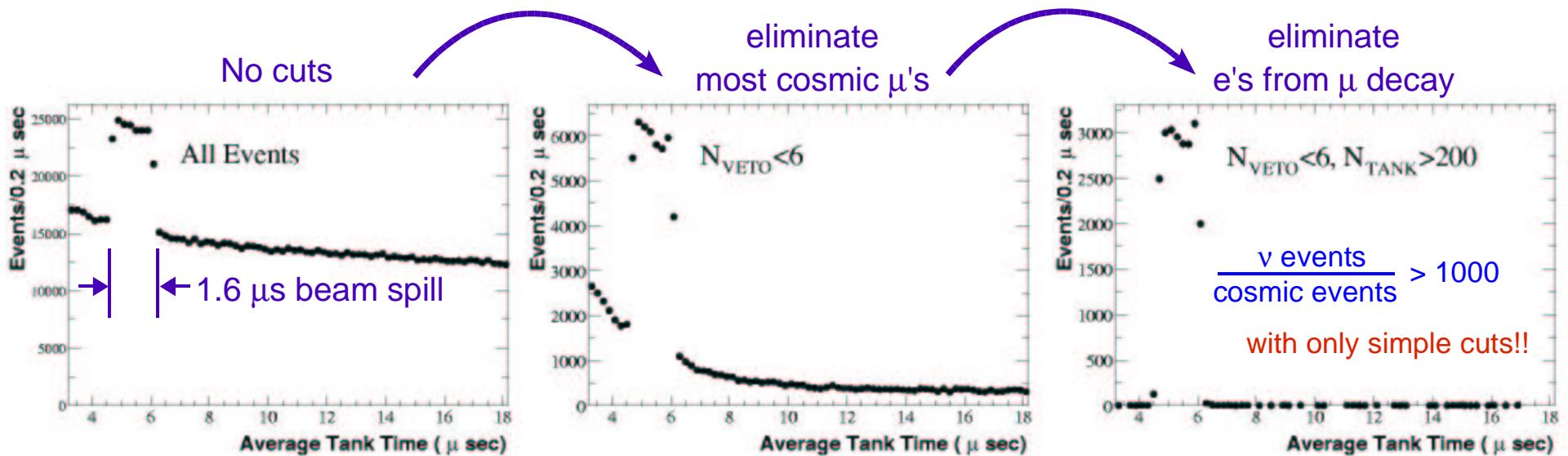
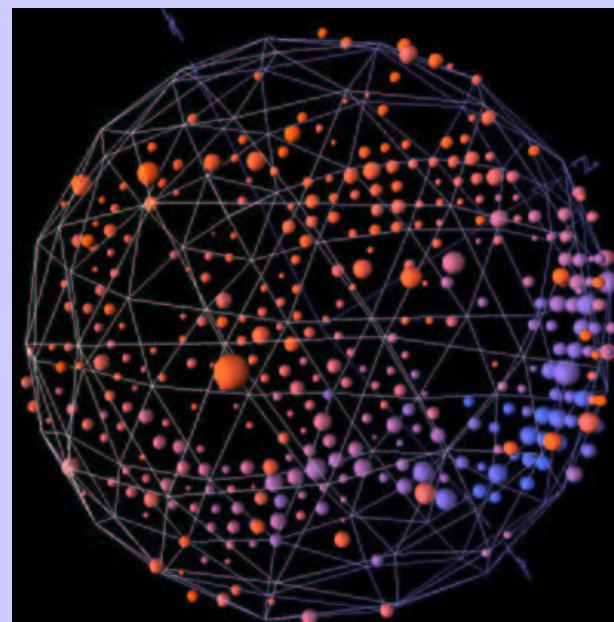
$$N_{VETO} < 6$$

No decay electrons

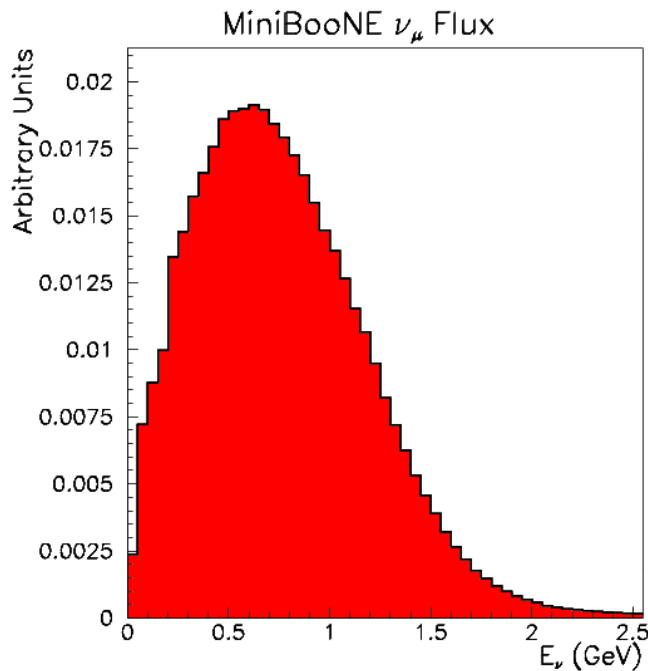
Ensure good reconstruction (Level 2 cuts)

$$R < 500 \text{ cm}$$

$$E_{\gamma 1}, E_{\gamma 2} > 40 \text{ MeV}$$



NC π^0 : ANALYSIS CHAIN



NUANCE V3
NEUGEN
NEUT

MiniBooNE
Detector
Monte Carlo
(Geant 3.21)

Data

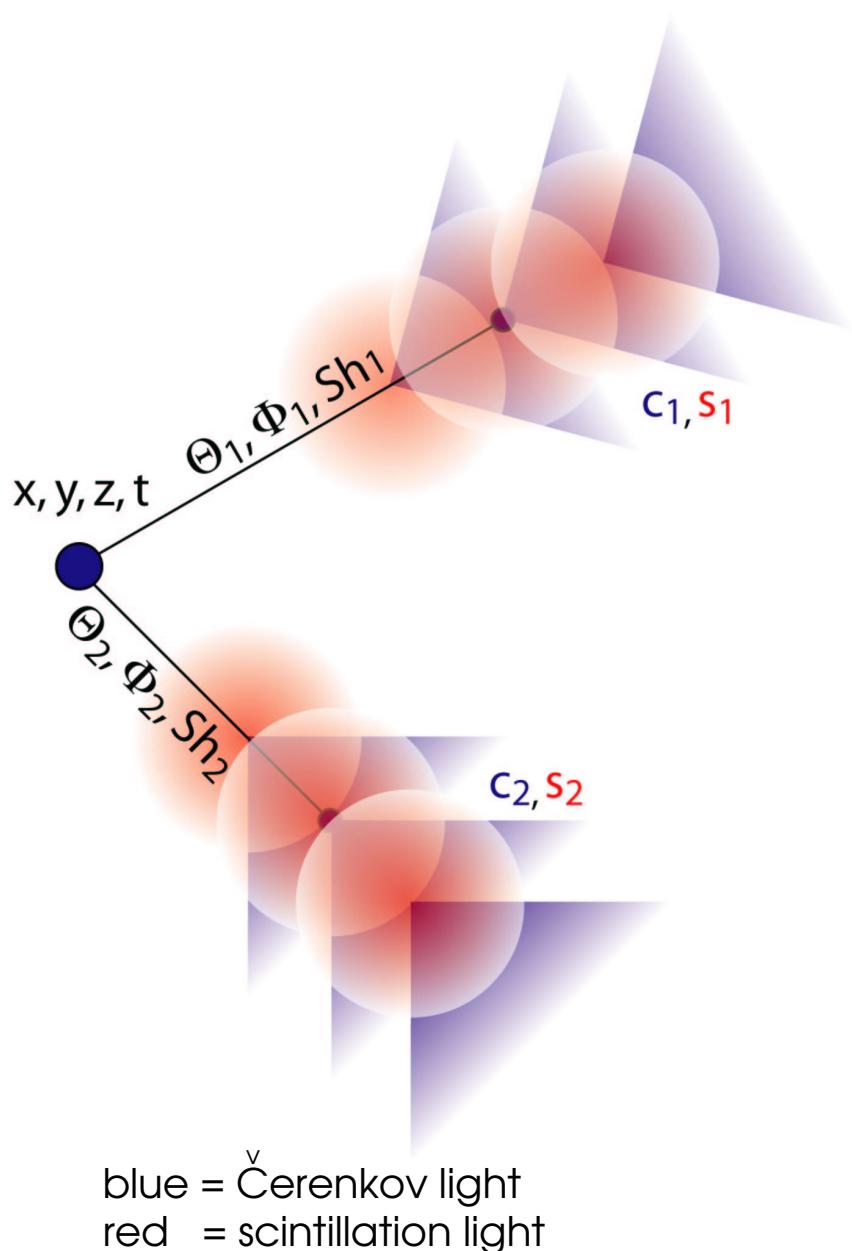
MiniBooNE
Analysis Framework
(reconstruction, etc.)

All Monte Carlo sets produced consistently:

- same ν flux (MiniBooNE)
- different cross section Monte Carlos
(different Fermi gas models, FSI & m_A)
- same detector Monte Carlo (MiniBooNE)
- same analysis (MiniBooNE NC π^0 selection)

Compare reconstructed
distributions

NC π^0 : RECONSTRUCTION



FIT EVENT ASSUMING TWO RINGS
(14 PARAMETERS)

- › decay vertex (4)
- › direction of γ 's (4)
- › mean emission points (2)
- › amount of Cerenkov/scintillation light (4)
- › Assumes e-like rings

DETERMINE EVENT KINEMATICS
(USING CERENKOV LIGHT)

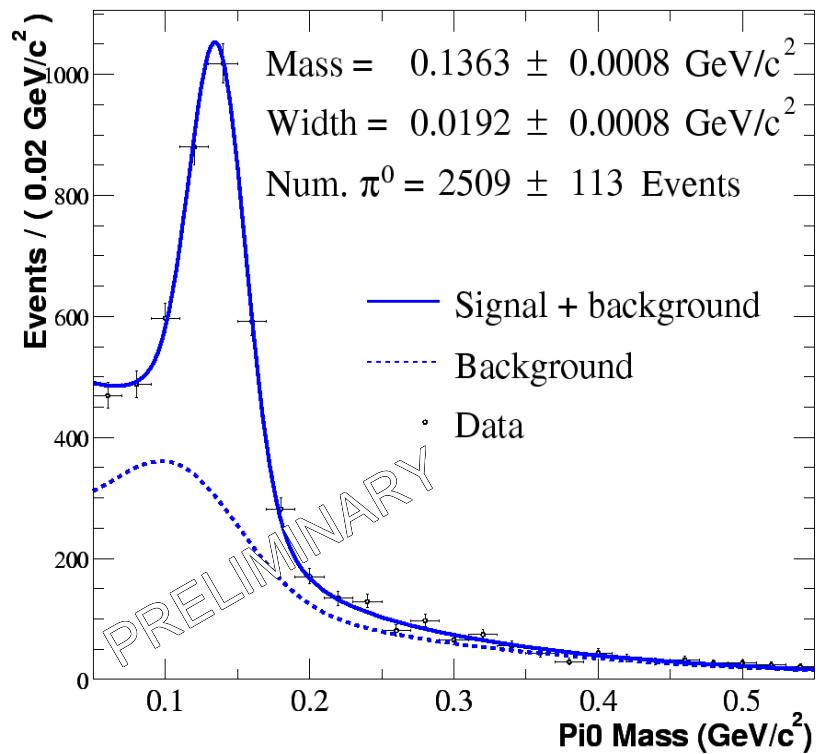
$$mc^2 = \sqrt{2 E_1 E_2 (1 - \cos \theta_{12})}$$

$$\vec{p} = E_1 \hat{\vec{u}}_1 + E_2 \hat{\vec{u}}_2$$

$$\cos \theta_{CM} = \frac{1}{\beta} \frac{|E_1 - E_2|}{E_1 + E_2}$$

DATA/MC COMPARISONS

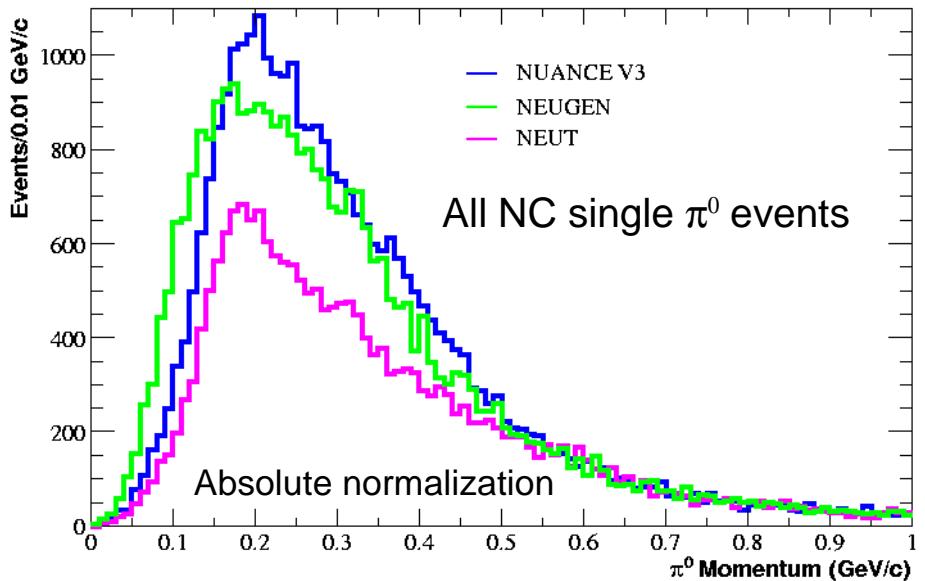
Monte Carlo	NC π^0 (%) (Res. + Coh.)	CCQE (%)	All bkgd (%)	Fitted Mass (MeV/c ²)
NUANCE V3	41	29	59	136.3 ± 0.8
NEUGEN	45	30	55	136.6 ± 0.8
NEUT	33	30	67	136.8 ± 0.9



Extended maximum likelihood fit to extract yield of signal π^0 's

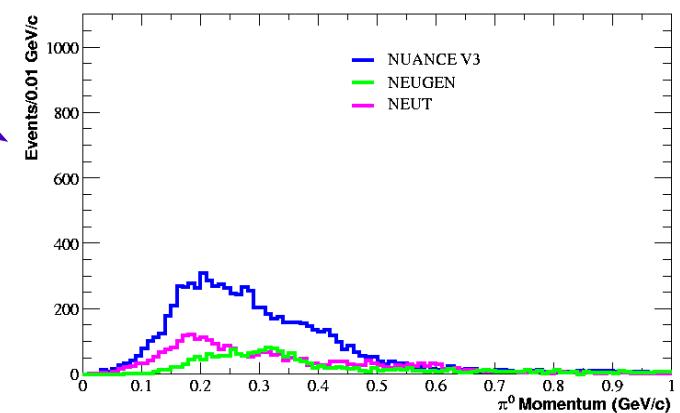
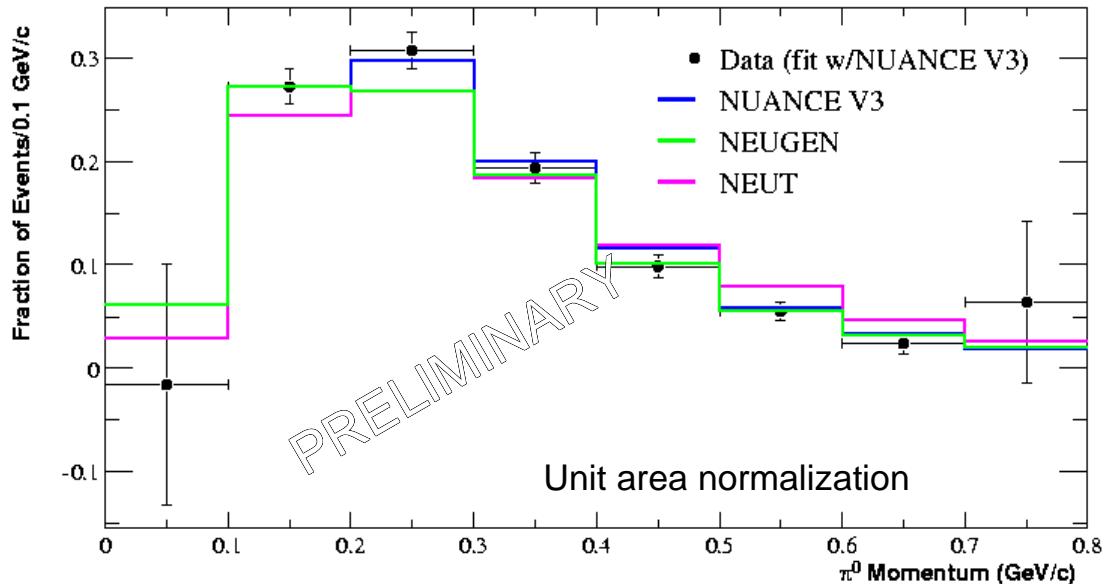
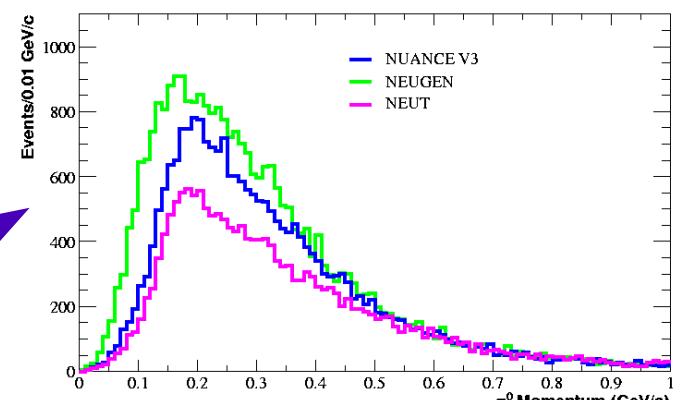
Fitted curves NUANCE V3-based parameterizations

COMPARISONS: π^0 MOMENTUM



Resonant π^0

Coherent π^0

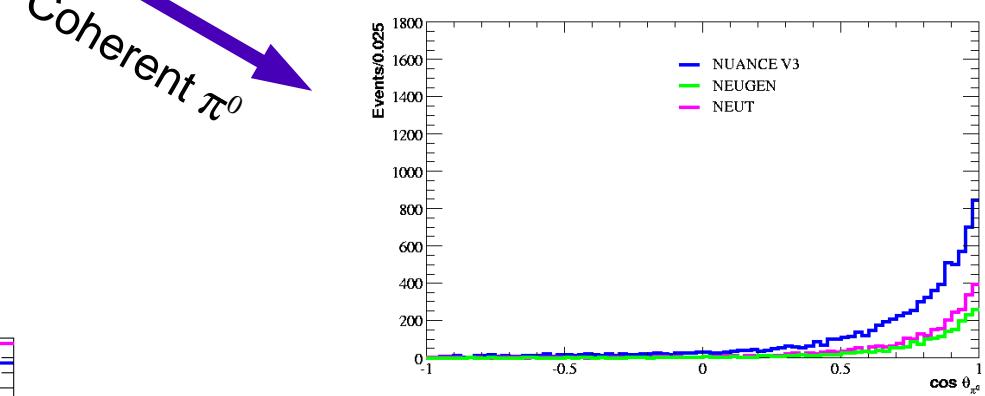
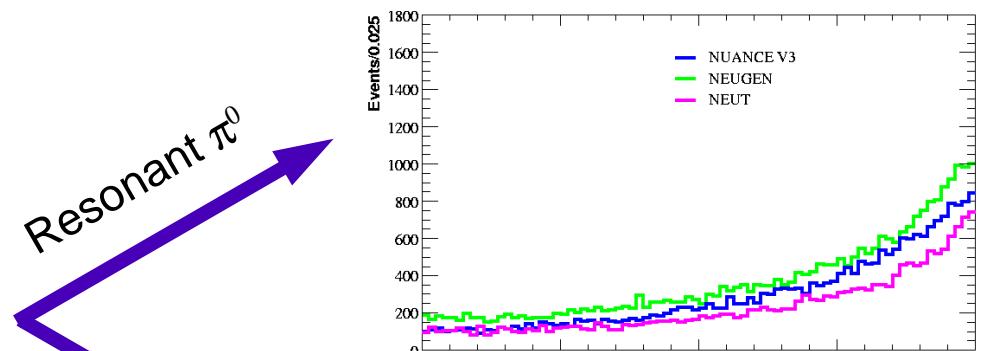
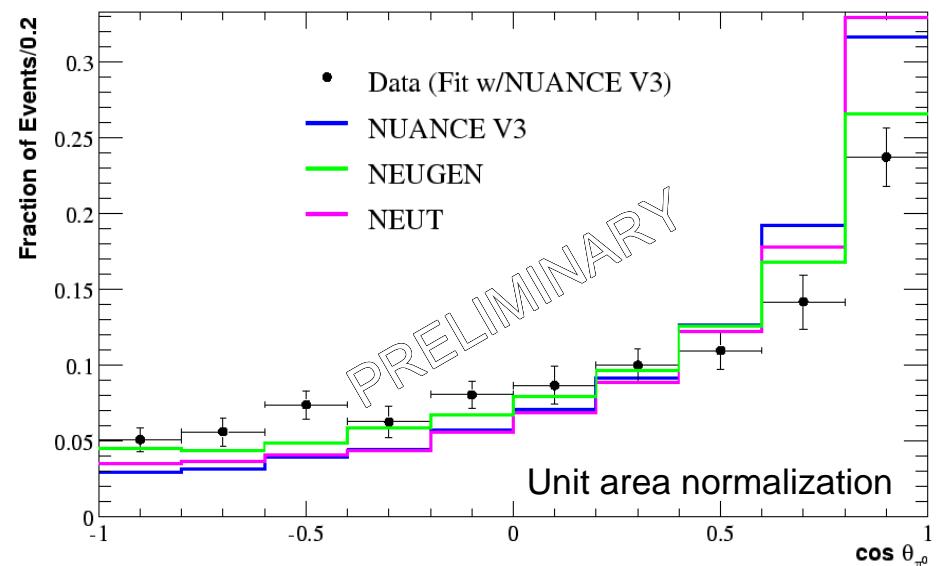
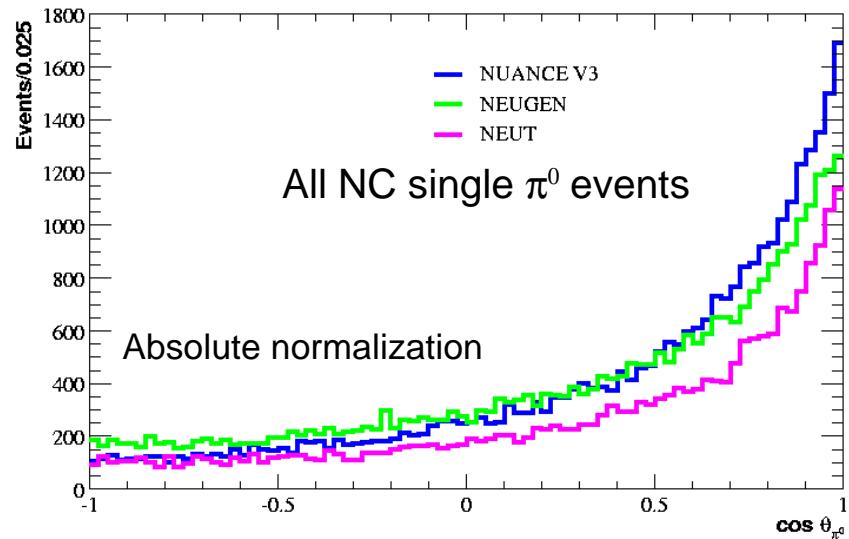


Fall-off at high momentum

- neutrino flux spectrum
- difficult to reconstruct overlapping rings

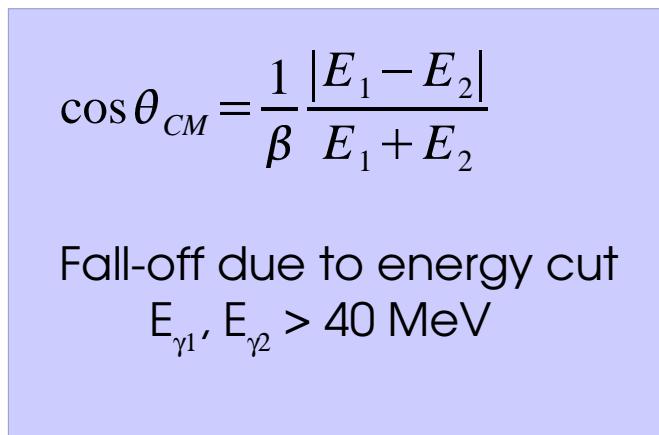
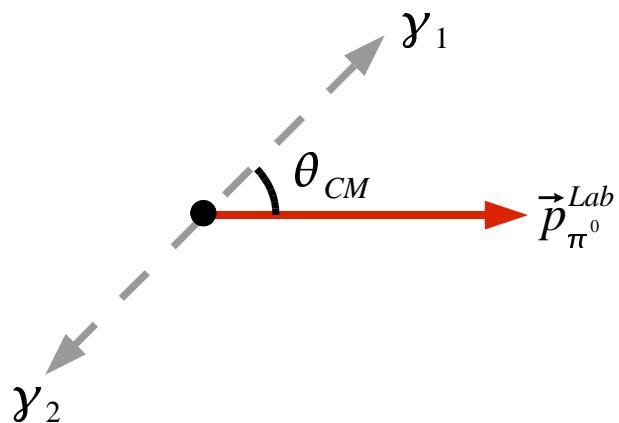
Good data/MC agreement

COMPARISONS: π^0 ANGLE RELATIVE TO BEAM

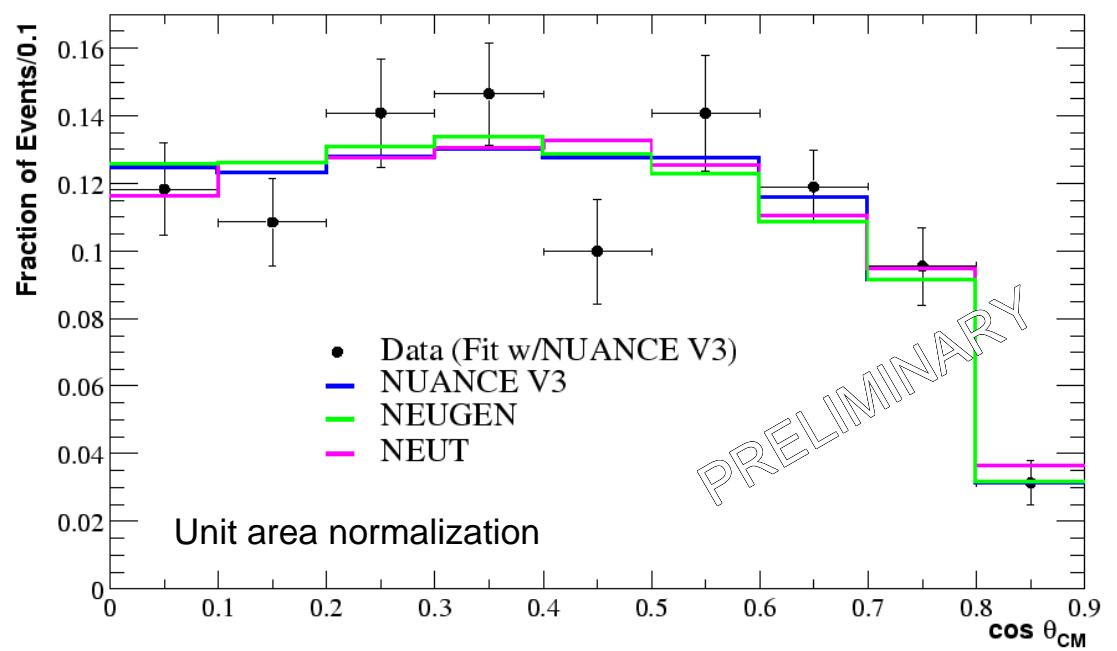


- sensitive to production mechanism
coherent: forward-peaked
- various models for coherent production with different predictions

COMPARISONS: $\cos \theta_{CM}$



- MC models data well
- Important for $\nu_\mu \rightarrow \nu_e$ appearance search
- ν_e CCQE will have large $\cos \theta_{CM}$



SUMMARY

Data/MC comparisons are encouraging
MC's all have similar shapes, except angular distribution
– expected difference due to different coherent contributions
but...

Serious lack of NC π^0 cross section data at low energies

Resonant NC π^0 :

- Only 1 data point for total NC π^0 cross section
- NC/CC ratio measurements not in agreement

Coherent NC π^0 : *What a mess!*

- At 1 GeV, compared to NUANCE
 - Marteau prediction x2 ↓
 - NEUGEN prediction x3 ↓
 - Paschos prediction x6 ↓
 - Oset prediction x20 ↓

Which one is right???

MiniBooNE hopes to help with this problem!

This talk has been made possible by

- your 3 favorite neutrino event generator czars
 - Dave Casper (NUANCE)
 - Hugh Gallagher (NEUGEN)
 - Yoshinari Hayato (NEUT)
- INFN, who generously provided travel support

Thank you!